FUZZY ALGORITHM FOR 3D COASTAL GEMORPHOLOGY MAPPING BY DInSAR

Maged Marghany and Mazlan Hashim
Department of Remote Sensing
Faculty of Geoinformation Science and Engineering
Universiti Teknologi Malaysia
81310 UTM, Skudai, Johore Bahru, Malaysia
Email: maged@fksg.utm.my,
magedupm@hotmail.com
mazlan@fksg.utm.my

KEY WORDS: RADARSAT-1 SAR, DInSAR, Fuzzy B-spline,3D, Coastal Geomorphology

ABSTRACT
This paper introduces a new approach for mapping coastal geomorphology by using intergeration between fuzzy algorithm and differentioal sysnthetic aperature radar interferometry (DInSAR). The basic concept of fuzzy algorithm was used to filter DInSAR data. The equation of phase difference was modified by involving the weighted least square method. Then fuzzy B-spline algorithm for 3D object reconstruction was modified based on the phase equation modified by weighted least square method to ensure 3 D coastal geomorphology reconstruction. The real 3D coastal geomorphology elevation have been collected along the shoreline of Kuala Terengganu Malaysia. The study shows the DInSAR provides information about coastal geomorphology change with accuracy of ± 0.2 m. It can be concluded that the integration between DInSAR and fuzzy B-spline can provide accurate map of 3D coastal geomorphology construction from historical RADARSAT-1 SAR fine mode data.

1.INTRODUCTION

The coastal geomorphology information is valuable for economic activities, for security and for marine environmental protection. Electronic theodolite is the classical system to map digital elevation of coastal geomorphology. Although this conventional technique can provide high precision results, it is very costly and time consuming especially when large area being surveyed. SAR (Synthetic Aperture Radar) interferometry is a relatively new technique for 3D topography mapping (Massonet and Rabaute, (1993). In this context, It could be a major tool for 3D coastal geomorphology reconstruction in real time. Furthermore, it could produce synoptic data over large areas at comparatively low cost. The coastal geomorphology features etc., spit, dunes and beach profile can be reconstructed by SAR interferometry. Differential Synthetic Aperture Radar interferometry (DInSAR) is new tool which is derived from SAR interferometry. Scientists and researchers have been defined InSAR as a technique that utilizes interference of waves for precise determination of distance (Massonet and Rabaute, 1993). In SAR interferometry, path length differences with millimeter accuracies can be detected based on the interferometric phase generated by conjugating two SAR images of the same scene at different times with slightly different viewing angles (Luo et al., 2006). According to Zekber et al. (1992), topographic information as well as movement information can be acquired from the phases. In fact, phases are corresponding to differential range change in the interferogram for two or more SAR images of the same scene. Recently, Luo et al., (2006) have introduced a technique which is based on utilization three pass differential interferometry (TPDI) to measure topography displacement. They reported that the displacement will be result in component called deformation phase in interferomateric phase, if the topography surface deformed at interval of SAR repeat pass.

In this paper, we address the question of utilization fuzzy-B-spline in 3D topography reconstruction before phase unwrapping. In fact, there are several factors could be impact the accuracy of DEMs was derived from phase unwrapping. These factors are involved radar shadow, layover, multi-path effects and image misregistration, and finally the signal-to –noise ratio(SNR) (Yang et al. 2007). This demonstrated with RADARSAT-1 SAR fine mode using integration between DInSAR (Luo et al. 2006) and fuzzy B-spline algorithm (Maged and Mazlan 2006). Four hypotheses examined are (i) fuzzy B-spline which is based on triangle-based criteria and edge- based criteria can be used as filtering technique to reduce noise before phase unwrapping. (ii) 3D topography reconstruction can be produced using satisfactory phase unwrapping (iii) high accuracy of deformation rate can be estimated by using the new technique.

2.0 METHODOLOGY

2.1 Study Area and Data Set

The study area is selected along the mouth river of Kuala Terengganu, Malaysia. According to Maged (2000) the coastline appears to be linear and orientated at about 45° along the east coast of Malaysia (Stanely 1985). In addition, spit was located across the largest hydrological communications between the estuary and the South China Sea i.e. mouth river of Kuala Terengganu (Maged 2000). Three RADARSAT-1 SAR images fine mode were acquired on October 30 1999, December 23 1999, and March 26 2004. The fine mode RADARSAT-1 SAR data are assembled as two interferometric pair. The image was acquired on December 23 1999 was selected as master image while the other pair of images are assigned as slave for respective interferomatric pair.

2.2 DInSAR-Fuzzy B-spline Procedures

Following, Luo et al. (2006) If the surface displacement is as a result of single or cumulative surface movement occurred between the acquisition times of three RADARSAT-1 SAR images S_1, S_2 and S_3, the component of surface displacement in the radar-look direction, ζ, contributes to additional interferometric phase as

$$\phi = \frac{4\pi}{\lambda}((R_1 - R_2) + \zeta) = -\frac{4\pi}{\lambda}((R_1 - R_3) + \zeta) + \frac{4\pi}{\lambda}\Delta r \qquad (1)$$

Where R_1, R_2 and R_3 are slant range from satellite to target respectively at different time, λ is the RADARSAT-1 SAR fine mode wavelength which is about 5.6 cm for C_{HH}- band. Finally Δr is the projection of displacement P_1P_2 on look of sight (LOS) $S_1 \rightarrow P_1$.

The phase difference, ϕ_d, only from the surface displacement as

$$\phi_d = \phi - \frac{\Delta R}{\Delta R'}\phi' = \frac{4\pi}{\lambda}\zeta\,. \qquad (2)$$

There are various de correlation factors can be effected the phase unwrapping such as geometrical, thermal, temporal, and Doppler centroid. These factors are contributed to reduce the signal-to-ratio (SNR). In fact, the phase unwrapping could be due to low SNR (Zebker et al. 1994). In this context, noise filtering is essential stage prior to phase unwrapping. In such tropical zone as Malaysia which is dominated by heavy vegetation covers which are the main source for decorrelation problem during InSAR or DInSAR procedures. This decorrelation might be effected of amplitudes of the complex master and slave images. Furthermore, Unreliability of the wrapped phases could be raised up due to decorrelation. Following, Yang et al. (2007), The degree of coherence $\gamma(j,k)$ can be defined based on the basic rule of fuzzy theory as

$$\gamma(j,k)=\begin{cases} \frac{\sum s_M(j,k)s_s(j,k)}{\sqrt{\sum\left|s_M(j,k)\right|^2\sum\left|s_s(j,k)\right|^2}}\frac{\min(\left|s_M(j,k)\right|,\left|s_s(j,k)\right|)-10^{-5}}{0.5} & if\ \ 10^{-5}<\min(\left|s_M(j,k)\right|,\left|s_s(j,k)\right|)\le 0.5 \\ \frac{\sum s_M(j,k)s_s(j,k)}{\sqrt{\sum\left|s_M(j,k)\right|^2\sum\left|s_s(j,k)\right|^2}} & if\ \ \min(\left|s_M(j,k)\right|,\left|s_s(j,k)\right|)<0.5 \\ 0 & if\ \ \min(\left|s_M(j,k)\right|,\left|s_s(j,k)\right|)\le 10^{-5} \end{cases} \quad (3)$$

where, s_M, s_s are the master and slave complex amplitudes, respectively. The numerical values 10^{-5} and 0.5 are threshold values used in this study.

According to Yang et al. (2007) the weighted square error is defined as:

$$w_e(j,k)=\sum_{y=-1}^{I}\sum_{x=-1}^{I}\gamma(j+y,k+x)\left|a_I(j,k)x+b_I(j,k)y+c_I(j,k)-s_I(j+y,k+x)\right|^2 \quad (4)$$

where s_I and *I=(s,M)* are donated both pixels location at *j,k* in slave and Master images while *y,x* donated the relative coordinates of adjacent pixel from *j,k* and $x,y\in\{-1,0,1\}$. Finally, $a_I(j,k), b_I(j,k)$ and $c_I(j,k)$ are the complex coefficient. Equation 2 can be written based on weight error as

$$\phi' = \phi_d + (1-(2s+1)^2-1)\frac{\sum_{y=-s}^{s}\sum_{x=-s}^{s}(\phi_d(j+y,k+x)-\phi_d'(j+y,k+x)-\bar{v}(j,k))^2}{\operatorname{var}(\phi_d+v)}(\phi_D) \quad (5)$$

where 2s+1 is window size which is taken here as 3 x 3, v is the additive noise, ϕ_D is sum of difference phase ϕ_d and *–v*. Then, fuzzy B-spline 3D surface topography reconstruction was introduced by Maged and Mazlan (2006), and modified to involve phase difference and correlation coefficient of master and slave complex amplitude patches is given by

$$S(p,q)=\frac{\sum_{i=0}^{M}\sum_{j=0}^{O}\phi' C_{ij}\beta_{i,4}(p)\beta_{j,4}(q)\gamma(j,k)}{\sum_{m=0}^{M}\sum_{l=0}^{O}\beta_{m,4}(p)\beta_{l,4}(q)\gamma(j,k)}=\sum_{i=0}^{M}\sum_{j=0}^{O}\phi' C_{ij}S_{ij}(p,q) \quad (6)$$

$\beta_{i,4}(p)$ and $\beta_{j,4}(q)$ are two basis B-spline functions, and $\{C_{ij}S_{ij}\}$ are the bidirectional control net.The curve points *S(p,q)* are affected by $\{w_e(j,k)\}$ in case of $p\in[r_i,r_{i+P+1}]$ and $q\in[r_j,r_{j+P'+1}]$, where *P* and *P'* are the degree of the two B-spline basis functions constituted the B-spline surface. Two sets of knot vectors are *knot p*=[0,0,0,0,1,2,3,……,*O,O,O,O*], and *knot q*=[0,0,0,0,1,2,3,….,*M,M,M,M*]. Fourth order B-spline basis are used $\beta_{j,4}(.)$ to ensure continuity of the tangents and curvatures on the whole surface topology including at the patches boundaries. According to Tsay and Chen (2003), the quality of determine DEM is function of the accuracy of GCPs which collected using GPS during the RADARSAT-1 SAR pass over on March 26 2004 along the coastline of Kuala Terengganu. Finally, height map is created and statistically compared with ground field data to acquire precisely coastal geomorphology 's DEM.

3.RESULTS AND DISCUSSION

Figure 1 shows the coherence image of topographic pair along the Kuala Terengganu mouth river. The coherence values is ranged between 0 and 1 where 0 value is represented incoherence and 1 is represented perfect coherence. However, in Figure 1 the high coherence value of 0.8 is corresponded to urban and sandy area while low coherence corresponds to vegetation zone due to the impact of deceleration in tropical area such as Malaysia.

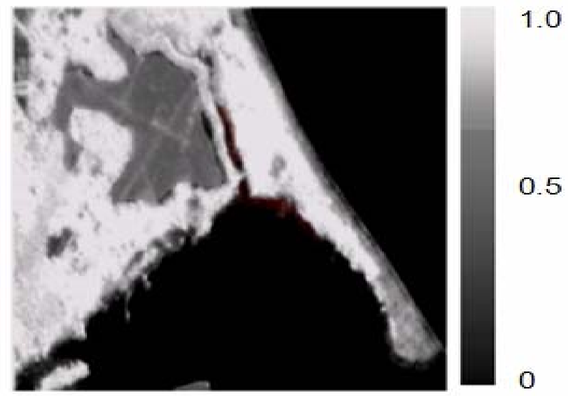

Figure 1. Coherence Image.

Figure 2 shows interferograms of two pairs. It is obvious that there is a great deformation was occurred in pair of December 23 1999, and March 26 2004(Figure 2b) compared to pair of October 30 1999 and December 23 1999(Figure 2b) . The topographic phase of Figure 2a was modulated into deformation the pair interferomateric phase of coastline (December 23 1999, and March 26 2004 (Figure 2b) to produce coastline surface geomorphology deformation. This can be seen along the spit. The 3D fringes are indicating the actual pattern of deformation along the coastline specially the spit area (Figure 3).

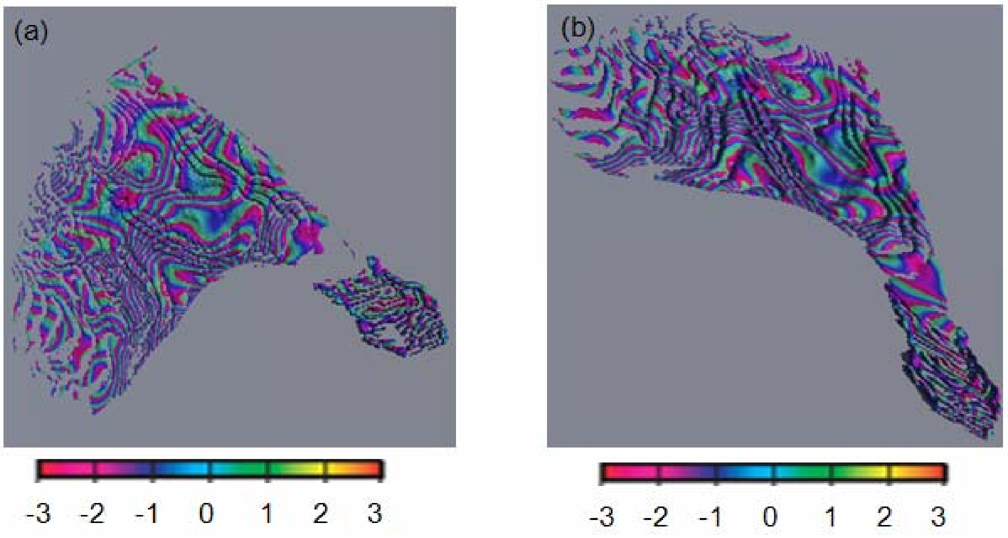

Figure 2: Interferogram of two Interferomatery Pairs (a) Interferogram of Topographic pair, October and December 1999; (b) Interferogram of Deformation Pair December 1999 and March 2004.

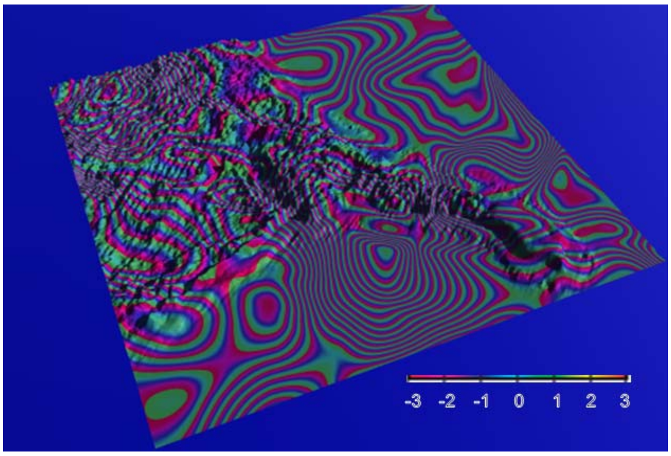

Figure 3. 3D Fringes of Deformation Phase Produced from Fuzzy B-splines

It is interesting to find that the coastal geomorphology patterns were exposed to tremendous changes since 1999 to 2004 (Figure 3). The rate change of spit is 3 m/yr with maximum elevation height of 2.4 m (Figure 4). Table 1 shows a good agreement between DInSAR s' DEM and ground data with r^2 of 0.86, p of 0.002 and rate of RMSE is ± 0.2 m. It is clear that rate of slope change is 1.5 m which considers as steep slope. It might be sand mining induced steep slope of spit. The increasing growth of spit across the estuary due to impact of sedimentation due to littoral drift. According to Maged (2003) net littoral drift along Kuala Terengganu coastal water is towards the southward which could induce growth of spit length. The high accuracy DInSAR s' DEM could be due to feed of fuzzy B-spline into unwrapped phase. In fact, integration between Fuzzy B-spline and DInSAR method has completely maintained the gradients on spit edges (Fuchs et al., 1997). Furthermore, fuzzy B-spline increased the rate of unwrapped phase accuracy. Indeed, fuzzy B-spline algorithm is able to keep track of uncertainty and provide tool for representing spatially clustered phase points (Russo, 1998).

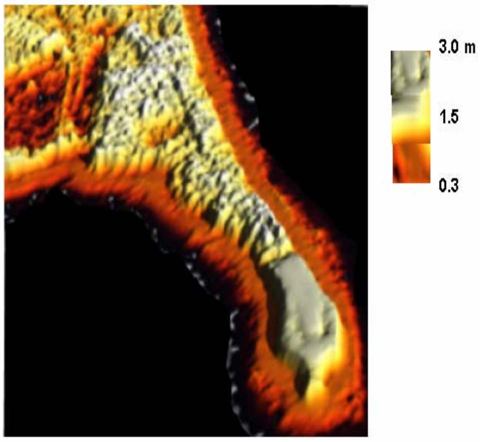

Figure 4: 3D Reconstruction of Spit by Using Fuzzy B-spline Algorithm

Table 1: Significant Relationship between Ground Data and Fuzzy B-spline Interferomatery

Statistical Parameters	Values
R^2 P RMSE	0.86 0.002 ± 0.2 m

4.0 CONCLOUSIONS

Historical RADARSAT-1 SAR fine mode data were used to demonstrate a new approach for 3 D reconstruction. The new approach is based on utilizing basic fuzzy concept and fuzzy B-spline for filtering phase noise and 3D reconstruction, respectively.Fuzzy basic algorithm and B-spline algorithm are implemented within phase difference and correlation coefficient of master and slave complex amplitude patches to map coastline deformation. The results has been confirmed that representing phase difference and correlation coefficient of master and slave complex amplitude patches by fuzzy B-spline is producing an excellent accuracy. Maximum height of spit is 2.4m and rate change of 3 m/yr within accuracy of ± 0.2 m . This study also shows the increasing length of spit across the Terengganu estuary within 2 m. It can be concluded that the integration between Fuzzy B-spline and unwrapped phase inteferogram can produce highly accurate 3D reconstruction of coastal geomorphology features.

Acknowledgements

We would like to express our appreciation to Universiti Teknologi Malaysia Research Management Center (RMC) for a great cooperation. In fact, RMC is providing excellent advice, plans and management for UTM researchers. We also acknowledge the financial e-science grants have received from the Malaysian Ministry of Science and Technology via its Intensified Research for Priority Areas programme.

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